Gail Purvis

Will compound equipment suppliers emerge into new business models? Veeco's recent publicity over its new 'Integration Center' suggests an industry restlessness and need to adapt to new trends. Will compound fabs look to new approaches? Their future may embrace the silicon outsourcing attitude and an emergence of a fabless compound community. Only handfuls of those are currently identifiable with InPhi Corp, Quake Technologies, Sirenza Microdevices, Endwave, Multilink and RF Solutions in the US and in Europe ACCO SA, Plextek and ThreeFive Photonics (hopefully about to emerge from Chapter 11). Finally, will compound device makers be able to adapt to mass production which will be required for some developing applications, the most obvious the forecast LED revolution? Alternately can they be cost-effective for niche sectors such as terahertz?

Emerging compound technologies & markets

Silicon's industrial history may provide some clues to the mass production route which compound may have to consider adopting. The current moves by SEMI and IMEC to include compound within their future plans will inevitably focus on the silicon preoccupation to scale down on size and up in unit numbers.

New developments such as chemically assembled electronic nanotechnology (CAEN), might be seen as the successor to silicon's computer integrated manufacturing for multi-supplier operations (CMSO). It's certainly attractive to the research phase of emerging nano compounds.

But other industries may provide better models for niche exclusivity. When the pizza sized 300mm wafer emerged into pilot lines, pioneers such as Infineon, apprehensive of the extensive need for automation, researched the car industry to see if its experience and production equipment layout approach (circular rather than linear) lent itself to adaptation by the fab, whose production processes have never been strictly linear.

It could be that the traditionally higher value compound sector should now be looking for production role models in sectors with high value similarities, such as pharmaceuticals, to gain the vital payoff to production approaches. And as the nano aspect looms, a pharmaceutical approach would have increasing attractions, as suggested by CTT's founder Dr Tony Vere [see Star gazing growth].

The build-operate-own model

Research by the Fraunhofer Institute for Systems and Innovation Research into the build-operate-own (BOO) model, points to an approach where mechanical engineers should prepare for a future where equipment suppliers will not only sell machines, but operate them for their customers.

In the automotive industry, cites ISIR, customers would rather pay a usage fee, based on production levels, than a one-off high purchase price. In volume silicon this approach was adopted years ago for test equipment where Hewlett Packard saw viability for small volumes of complex chip testing to run at one price on equipment that held the immediate potential to accept raised revenues for larger and more complex volumes, at the flick of the test equipment's switch.

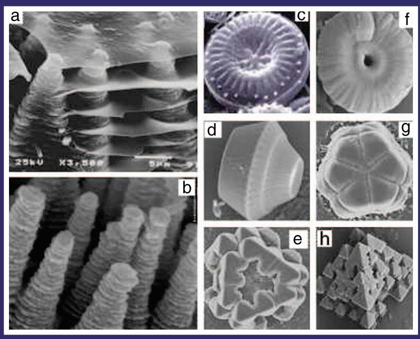
Utilities, such as gas, have moved progressively from volume supplies in BOO site facilities, extending these to share with companion power utilities, and offering complete facilities management including staff and maintenance for industry.

In its recent '*Innovation in Production Survey,*' project director of the study Gunter Lay says that "current widespread skepticism among suppliers regarding 'build-operate-own' is only partially justified. "These systems create new opportunities for innovative suppliers in stagnating markets."

According to his survey, manufacturers of auxiliary equipment, such as air conditioning units and pumps, now rely on BOO models to differentiate themselves from competitors.

Companies offering the BOO model are also well positioned, and gaining experience with accompanying services, such as consulting, training, maintenance and repair. BOO models are at the end of a long service chain, though, warns Lay, and they need "new controlling concepts and specific product configurations."

The ISIP survey shows that a tenth of suppliers offered to take over operations of machines for their customers. In manufacturers of complex systems, that rate is even higher, at 20%. Major customers are primarily concerned with cost and



Early days in chemically assembled electronic nanotechnology (CAEN) at Sandia Research Laboratories show complex nanostructured crystals have been prepared with strong similarities to those observed in biominerals. (a) is nacre in red-abalone. (b) is synthetic ZnO crystals. (c) is a diatom. (d) to (h) are different types of synthetic silica crystals. Morphology depends on the growth conditions and is controlled. Sandia researchers are working on nanoscale material manufacture, a significant scientific and technological challenge. Most of the approaches currently investigated involve high-temperature processes and complex toxic chemistry. A challenge now is to fundamentally understand how organic molecules affect crystal growth. Jun Liu, manager for the Department of Chemical Synthesis and Nanomaterials at Sandia said this is not only a challenge for synthetic materials, but also a problem for biomineralisation that needs the attention of physicists, chemists, biologists, and material scientists.
Another challenge is developing general rules that will guide the production of a wide range of nano materials. Liu said the team is also in the process of developing tools to control the delivery, diffusion, and transport of the chemical species in the reaction chambers.
"We will use Sandia's state-of-the-art microfluidic platforms to provide precise control of the experimental parameters," Liu said. "The microfluidic studies may also lead to methods for continuous manufacturing of tailored nanoscale materials, including nanoparticles, nanowires, and complex nanostructured films."

budget aspects. But in smaller companies, employees are being overwhelmed by the task of operating machines of growing complexity.

It's a model that may appear foreign to the compound sector, but it could have real validity. Lay recommends that innovative suppliers should target their BOO models to this niche market, allowing them to win new capital-poor customers, daunted by the purchase of expensive machinery.

There will be more of those in future if compound is to follow a route increasingly caught up with silicon and nano. Moving from high value, limited output to lower value mass output is a model that the LED sector will be swept into. A domain for only a few volume producers, there look to be niche sectors, such as the health market, where light and lasers are increasingly emerging successful.

Accommodating to nano

Either as a competitive or complementary product, compound semiconductors are also going to have to accommodate to the dictates of nano technology and all that that implies by way of complex and increasingly expensive inspection, monitoring and handling equipment.

Patents on nanotechnology are beginning a ground swell as any desultory search will show. From July 3, 2003, applicant the Regents of the University of California on a nanowire optoelectric switching device and method. Or Genoptix Inc in October awarded a patent for early detection of apoptotic events and apoptosis using optophoretic analysis and a July patent on a method of using optical interrogation to determining a biological property of a cell or cells. In January an inventor Oleg A. Yevin won a patent for nano and micro metric dimensional systems and methods for a nanopump based technology.

While carbon nanotubes dominate at present, many of the patents are generically wide enough to include compound materials.

There's not much suggestion at present that the compound equipment suppliers are considering nanotechnology which the experts reassuringly say will remain in the laboratories for another decade.

But equipment manufacturers for compound fabs are intriguing bellweathers, having to remain one step ahead of client's needs. Their solutions are pragmatic.

So while material wafer sizes continue to grow from 2" to 4" and some start the struggle to 6," newer production models allow for a variety of wafer sizes, with a volume batch wafer approach. If one 300mm unit is physically impossible, then 30 at 10mm is the next best option.

Increasingly compound production equipment acknowledges the importance of in-line computer control for the numerous parameters of gas, temperature, doping, area uniformity, air flow *et al*, critical within extremely narrow latitudes and dimensions.

This means increasingly developing equipment that allows for fast, reactive operator or controller-computer reactions, in a closed loop system. Expect much more of the same as the nano devices start to emerge into production.

As example IMT's subsidiary, Insight Analytical Laboratory of Santa Barbara has recently expanded its capabilities for topography, surface structure dimension, identification of organic materials and firm thickness measurement with profilometry, FTIR spectroscopy and ellipsometry, as well as its existing SEM, AFM TEM, XPS, SIMS and FIB/SEM capabilities.

KLA-Tencor's moves into inline metal film metrology may be aimed at the copper barrier seed and nitride composition in gate dielectrics, but it admits that the heavy R&D into integrating these and new compound alloys such as SiGe and tantalum nitride at 65nm is another developing sector, as is the monitoring of silicon oxynitride transistor gate dielectric films for 90nm applications.

Increasingly computer control requires successful software, modelling and simulation development. There are niche development sectors that the IT sector should not ignore. These give the vital features embedded in increasingly expensive manufacturing equipment, that will however meet the required volume production quality. Maximising on this cost return could well call for a fresh approach to supplying equipment capital poor but potential growth market.

Equipment to handle nanotechnology has been rapidly emerging in the last few years, from 3D device viewing to light tweezers manipulation devices to the emergence of a commercial optical processor, but for implications of where devices and technologies will go, the place to brood at is at the US National

Institute of Standards and Technology. [http://www.mel.nist.gov/proj/toc.htm]

It has a nano to millimeter manufacturing programme with an expected 'output' for the route forward.

Work back from NIST '07

In 2003: Virtual Environment (VE) technologies and supporting formal representations that support the display of torque and force interactions between molecules through visual, audio, or haptic modes, under the user's discretion and control. 2004 is the optical instrument and demonstration of the ability of integrated optical system (optics, electronics, and software) to trap, manipulate, and measure micrometer and sub-micrometer parts with irregular shapes. This includes initial control interfaces between physical resources and the VE. By 2005 phase, the moves are optical instrumentation to demonstrate integrated heuristic user interface (eg VE) for measurement and manipulation of nanodevices with a closed feedback system that links the calculated position/orientation with those displayed in the VE.

The final optical instrumentation phase, around 2007, will demonstrate feasibility by developing methods for achieving traceability of force measurements, proving these through assembly and measurement of devices from external partners.

There's an intriguing market there. It's going to call for some interesting IT solutions as well as innovative hardware! But if you really want to be awed, consider nanometer scale metrology.

New metrology futures

By 2007, NIST intends to develop and implement with industry, a first-ever accurate shape sensitive line width computer model to improveaccuracy of line width measurements in semi manufacturing.

It will implement a mask-less lithography system capable of fabricating sub-100nm test calibration structures and have the capabilities to perform simultaneous dimensional and electrical measurements using SPM techniques relevant to nano tech, microfluidics and semiconductor industry applications.

It will develop standards and procedures needed for traceable measurements of feature sizes on IC photomasks, composed of binary and/or phase shifting features to improve the accuracy of line width measurements in manufacturing and develop and put in place high accuracy SEM measurement capability, and a set of relevant standard artifacts for dimensional metrology of 100nm and smaller structures.

Then there's the design completion and implementation of an optical-based overlay metrology system for disseminating new methodologies, and calibration and distribution of SRMs for feature overlay on silicon wafers to improve accuracy of linewidth measurements in manufacture. Tools and methodology will develop to enable routine diode laser interferometry measurements and atom-counting to be applied with the UHV-STM on etched silicon features demonstrating sub-nanometer accuracy.

Packaging structures

Wafer and device sizes and dimension may be one part of the compound coin. The other is packaging. Since compound is meant to be faster, more flexible, better tolerant of heat, and generally more adaptable, its packaging can be a real sticking point, not just for extremes of temperature but for the newer developments such as bionics, where a 3D system in a package (SIP) approach is still going to need to answer some extremely subtle problems.

For compound the major approach appears to be towards 3D. Historically the silicon ball grid array replaced package leads; arrayed solder bumps shrank in size; increased in/outputs enhanced the performance and process. This was followed by the chipscale package with 2D at nearly bare die size.

Now wafer thinning technologies producing dies down to 50µ are looking to the inevitability of 3D multi-stack package solutions. Being mulled over at present, packaging is an emerging sector with a wide range of options for silicon; a quandary for compound, and a cloud on the horizon of nano.

In the consideration of GaN (AlGaN/GaN) SiGaN substrates, SiC and SOI CMOS aired at the 2003 Hiten high temperature conference, speaker after speaker acknowledged that lack of standards, small markets and major problems of packaging and interconnects were still real stumbling blocks. Wayne Johnson of Auburn University who gave the master class in high temperature assembly, defined temperatures needs at 125°C to 150°C for automotive; from 150°C to 200°C automotive [80-90% of the high temperature market]. Up from 200°C was wanted for for oil well logging, geothermal and aircraft and upward of 300°C for military, aircraft and aerospace.

More recently expert George Harman, an authority on materials for microelectronic interconnections and packaging at the National Institute of Standards and Technology (NIST), made a workshop presentation for NASA engineers at the Jet Propulsion Laboratory on designing semiconductor device interconnections to withstand extreme space environments.

He recommended that space bound microelectronics interconnections be made with corrosion resistant, highly stable metals, especially gold. He also suggested the use of some newer polymers that can withstand extreme temperatures, but are not yet used in the space programme.

"Flip chips" was his other approach, that with proper metallurgy may make sense in high-temperature planetary environments. Instead of wire leads around the edges of a microchip to export electrical signals, flip chips normally use a pattern of ball-shaped solder contacts that are attached directly on the chip surface. Harman suggests that NASA consider using flip chips designed with gold contacts to produce spacecraft electronics that are both space-saving and heat resistant. As the 3D package platform roadmap shows variety abounds. Laminates or flex circuit substrate, wire pad bond, flip chip, conductive, adhesive or combine interconnect, stacked pyramids, overhang, fold over, mixed technology stack with flip chip and lead free solder balls. The range and variety suggests that a final few winning classics are still to be proved.

Next issue Part II. Devices.